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THE BARRIER SYSTEM FOR CONTROL OF FLOODS IN MOUNTAIN STREAMS[1]

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INTRODUCTION

The control of floods occurring in mountainous areas of the Western States has been a serious problem for many years. A particular and peculiar problem is found at mouths of steep canyons, where the streams leave the mountains and enter broad valleys or comparatively level areas. In many cases the canyon floor has been eroded down to the rock, while the sides are old lake-bed gravels, standing at unnatural angles of repose, because of the erosive action of flood waters. The detritus washed down from the mountains has built up debris cones at the mouth of these canyons, extending from the steep mountain slopes on to the flatter lands of the valley floor. The lateral and terminal edges of these cones flatten out and the slope of the cone is less steep as the valley floor is approached. These cones are better drained than adjacent land and are near the water supply, so that they are especially desirable for farming and in many cases have been used for town sites. When floods come down the canyons, these lands are inundated, and covered with sand, gravel, and boulders; irrigation ditches are filled with debris, and oftentimes buildings and improvements are destroyed by the flood. It is the heavy load of debris

[1] Prepared in cooperation with the Utah Agricultural Experiment Station.

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carried by these floods, rather than the excessive volume of water, which makes flood control especially difficult.

Some 10 years ago the Bureau of Agricultural Engineering was called upon to devise a method of flood control which would prevent damage and injury to irrigation canals and structures in Utah. As a result of this work a barrier system of control has been developed that has proved successful. Seventeen such systems have been constructed in Utah during the past 10 years, and all are furnishing complete protection at reasonable costs. The system can be adapted for use under a wide variety of physical conditions.

FLOOD CHARACTERISTICS OF MOUNTAIN STREAMS

There are two quite distinct classes of floods in mountain streams. There are spring freshets caused by rains and melting snows, and torrential floods of short duration caused by cloudbursts. As a general

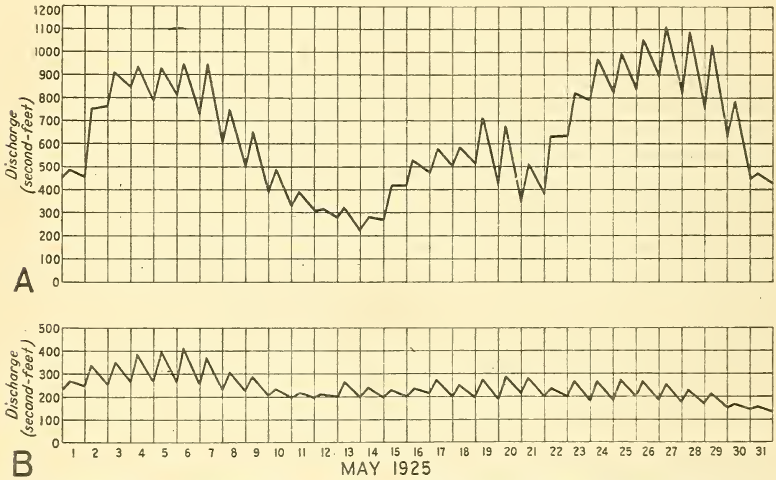

FIGURE 1.—Daily fluctuations of two mountain streams in California during the spring run-off: *A*, Falls Creek near Hetch Hetchy, Calif.; *B*, South Fork of Toulumne River near Oakland recreation camp, Calif.

thing, the greater part of the run-off occurs in the spring, and the spring freshets may be active from 3 to 6 weeks and show daily fluctuations. The flow during periods of cool weather may drop to normal and may rise on hot days, following warm nights, to the stage of moderate floods. Usually there is a wide fluctuation between day and night flow, as indicated by the graphs in figure 1.

In Utah the greater part of the total annual run-off of mountain streams is delivered early in the year, usually during April and May and always before the middle of June, as shown in figure 2. In some cases the run-off from melting snow begins as early as January. Spring freshets from watersheds subject to summer floods carry large quantities of boulders, sand, and gravel into the lower reaches of the stream. Where storage reservoirs are not available, it is necessary to utilize the spring flood waters by turning them directly into the irrigation canals, since generally there is much more land under the ditch

than can be irrigated by the normal flow of the stream during the growing season. In order that this water may be of maximum benefit to the users, it should be delivered to the canal systems free from detrital material.

The floods which do the most damage are occasioned by cloudbursts occurring usually in midsummer and over very limited areas. These torrential floods are generally of short duration and seldom continue longer than an hour. It is not unusual for the first stage of such a flood to consist of a rolling wave of mud and debris which moves down and out of the canyon with terrific force and great speed.

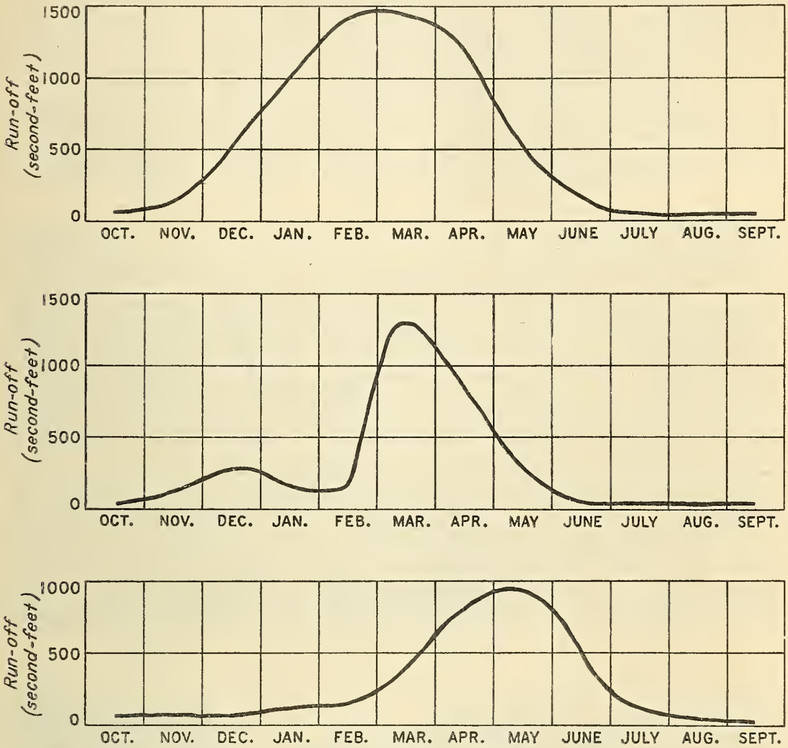

FIGURE 2.—Distribution of the annual run-off from three typical mountain watersheds in Utah.

These floods do far greater damage than the spring freshets, as they often destroy buildings and structures and leave vast deposits of boulders, stones, and gravel in their wake. The views in figure 3 indicate the character of the debris brought down by torrential floods.

THE BARRIER SYSTEM OF CONTROL

Nature in the building of detritus cones has shown a way in which flood waters can be kept within bounds and the waters unloaded of their debris. Figure 4 shows typical natural cones as found at canyon mouths in the Wasatch Mountains in Utah. The barrier-control plan is an artificial system of cone building in which use is made of the law

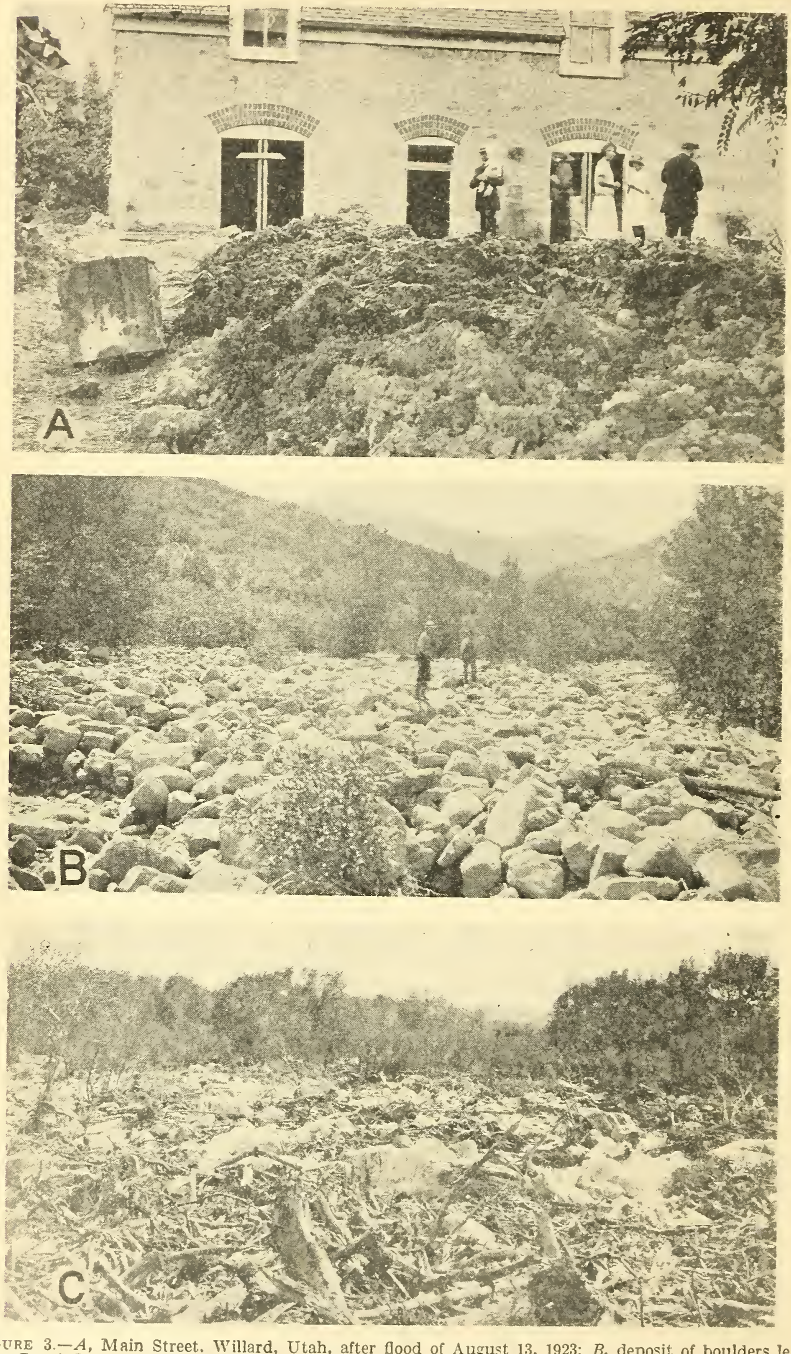

FIGURE 3.—*A*, Main Street, Willard, Utah, after flood of August 13, 1923; *B*, deposit of boulders left by Canal Creek flood, July 1922; *C*, debris deposited above Farmington, Utah, barrier by the flood of July 3, 1926.

of hydrodynamics that the transporting power of water varies with its volume and with its velocity. The plan is to spread the water as it emerges from the canyon, thereby decreasing its velocity. The larger debris is deposited almost immediately as the flood spreads out at the mouth of the canyon, and the finer material settles in a stilling basin above an artificial barrier. The essential features of this system are: (1) The barrier, or cross dike, (2) spillway, (3) lateral dikes, (4) stilling pool, and (5) temporary drift dams. All of these features are shown in figure 5.

AREA OF WATERSHED AND ITS RELATION TO DESIGN OF CONTROL WORKS

The quantity of flood water and of debris to be taken care of cannot be estimated accurately, since there are very few records of flood flows and because the usual methods of estimating flood heights can-

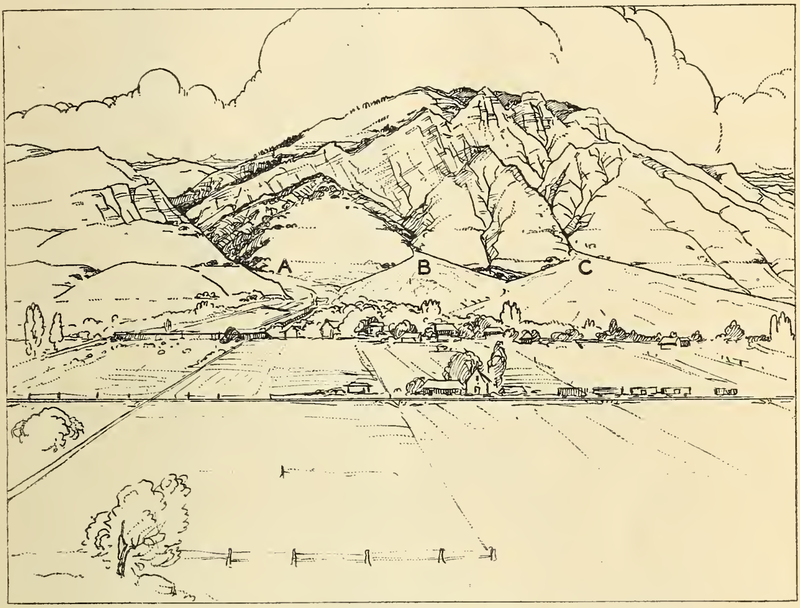

FIGURE 4.—Typical physical characteristics of alluvial fans in the Wasatch Range, Utah: *A*, Vertex of large cone formed by continuous stream; *B* and C, vertexes of small steep cones formed by torrential floods.

not be used. A very destructive flood may result from a cloudburst covering only a small area, such as one quarter of a square mile, while the total watershed area may be 100 square miles or more. Again, in many areas such as Utah and southern California, the area of the watershed is less important, when considering spring floods, than the percentage of the area which contains gravel and boulders. Floods are closely related to methods of watershed management, as is shown in a preliminary report by the State of Utah in cooperation with the United States Department of Agriculture.

LOCATION OF BARRIER AND DIKES

The primary consideration in fixing the site of a barrier system is a comparatively broad and even area over which the flood can be spread and upon which the debris can be deposited. The location of

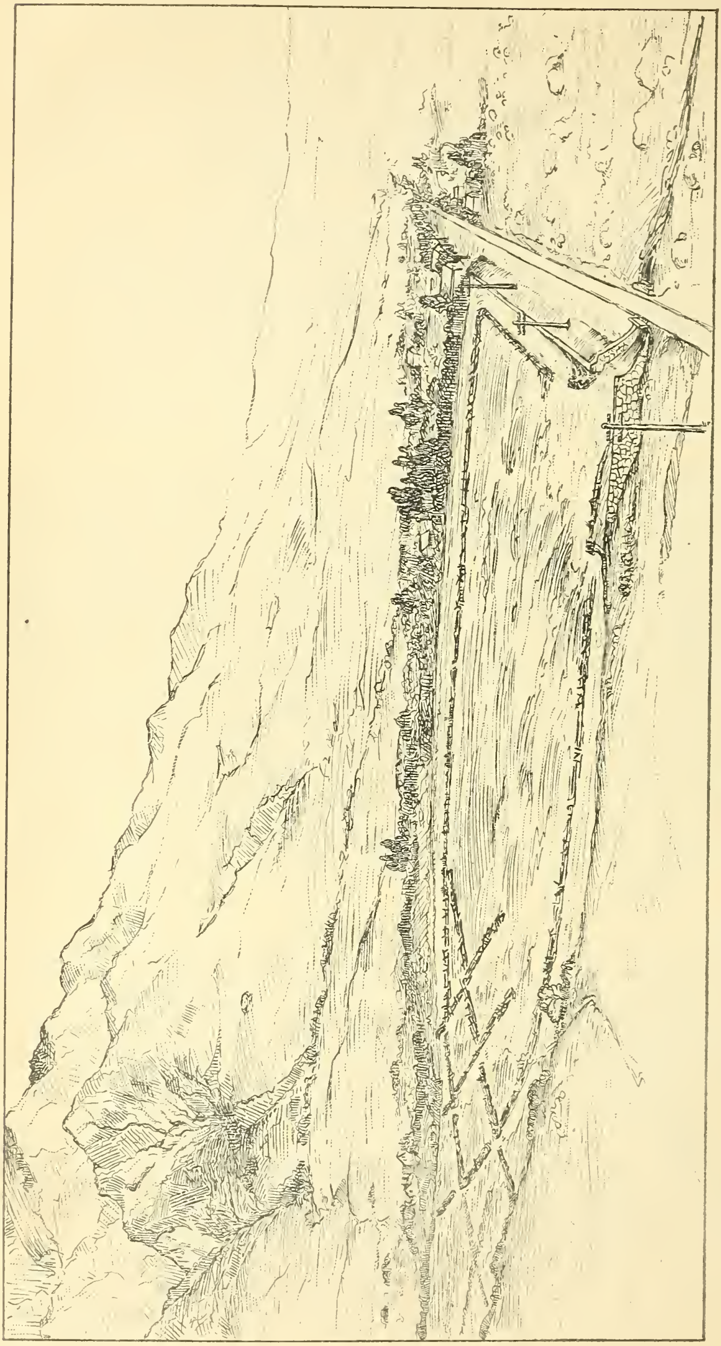

FIGURE 5.—Principal features of a barrier system of flood control.

control works within narrow canyon walls is seldom effective because of the limited amount of spreading and the smallness of capacity for the storage of detritus. In some instances mountain streams, as they emerge from their canyons, have cut their way through gravelly benches, and the bed of the stream or the river bottom widens out as the distance from the canyon increases. In such cases, where the width of the river bed is three or more times that of the channel, the barrier may be placed in the river bed. In general, however, the barrier system will be located upon the surface of the detritus cone below the canyon mouth. The cross barrier should be located at some convenient and suitable place far enough below the mouth of the canyon so that the land is comparatively flat. Its exact location will be determined by the availability of suitable land for the spreading, by property lines, and by the location of the property to be protected. Generally, it will be necessary to build lateral dikes from each end of the barrier to the canyon walls in order to limit the amount of spreading. Since the size of the floods and the amount of debris to be taken care of cannot be estimated accurately, because they are independent of the size of watershed and other factors used in predicting the size of floods, the location of the barrier and side dikes is generally determined by local conditions of topography and land ownership. Within reasonable limits, the greater the distance between the side dikes the better, because the greater that distance is the shorter may be the distance between the mouth of the canyon and the barrier. If the conditions are such that only a small area can be economically enclosed, greater capacity may be secured by increasing the height of the dikes and barrier.

ELEVATION OF BARRIER AND DIKES

The embankments must at all times be high enough to prevent overtopping. No two floods and no two canyons will carry down in any one or succeeding year the same amount of material. Therefore the engineer must determine for himself the amount of freeboard necessary to start out with each spring. The cross barrier and the dikes are raised possibly for each flood or each year or at such other intervals of time as may be necessary. Sometimes two or three cloudbursts will occur in a single year and then there may be a period of several years without a cloudburst. Usually there are maintained from 3 to 5 feet of freeboard on the barrier and 2 to 5 feet on the dikes.

CONSTRUCTION OF BARRIER AND DIKES

The barrier and dikes are built out of whatever material is available at the site, and may be sand, gravel, or boulders or earth banks protected with gravel or crib facing (fig. 6, *A*). It is not necessary that these structures or their foundations be impervious, since their purpose is to arrest the movement of the water and to guide its direction of flow. Dikes which were pervious when constructed often become impervious through the silting up of interstices.

An important principle of the barrier method of flood control is the use of the spring floods, and the debris which they carry, to furnish the material required for raising the dikes and the barrier. By means of diagonal barriers in the channel, the spring floods are diverted first to one and then to the other side of the basin, and their load is deposited along the front of the side dikes, to be placed later on top of

the dikes by the use of teams and scrapers. The early and late stages of the spring flow are concentrated and the load carried to the foot of the cross barrier, where the material is deposited for use in raising the barrier. In this way the power of the flood is used to deposit

FIGURE 6.—*A*, Scraping gravel to outer edge of dike at the close of a season; *B*, fence of woven wire used for a drift dam.

material for increasing the height of the dikes and barrier where it can be used advantageously.

THE SPILLWAY

The size of the spillway is determined most frequently by the judgment of the engineer, as in few cases are there any flood-flow records.

The capacity of the spillway is determined as in any other engineering work dealing with water storage. The essential thing is to have it of sufficient capacity. The spillways are built of rubble masonry, concrete, rock-filled cribs, boulder mattresses encased in wire netting or other similar materials. The elevation of the floor of the spillway must be such that a stilling pool will be formed above it. For this reason, the floor of the spillway must be raised from time to time as the stilling pool fills up with silt. The foundation need not be impervious, but where the spillway rests upon fine alluvium or clay it is desirable to provide against the soil becoming waterlogged, which would be followed by the settlement and possible cracking of the structure.

The best design for a spillway is bowl-shaped, with the crest in a semicircle and with the downstream wing walls blended into the arch of the crest so that there is no marked line where crest or floor ends and wall begins. Construction of this type is stable, and may be built safely upon foundations generally considered insecure for masonry. The semicircular crest deflects the flow toward the center of the stream where the converging currents counteract each other to decrease the velocity of outflow. The water cushion formed by the bowl-shaped apron aids in this result and spreads the stream over the downstream apron level with the stream bed, which minimizes any tendency toward erosion at the lower toe.

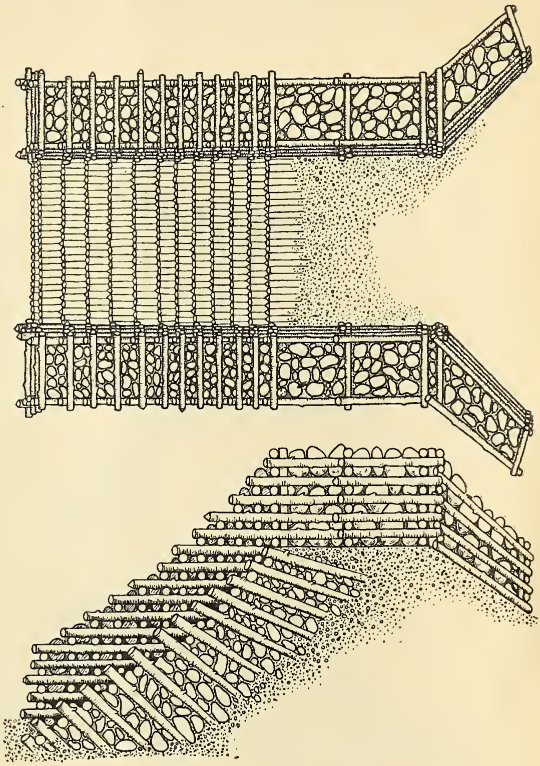

FIGURE 7.—Timber spillway of type A.

TIMBER AND ROCK

Figure 7 illustrates an early type (A) of timber and rock spillway which has been successfully used at Nephi, Fillmore, and Kanosh. Since such structures are quite permeable, sheet piling or concrete aprons and cut-off walls, extending well back into the barriers, are sometimes necessary.

To avoid leakage through and around the wings of later structures, the modified design of wing construction (type B) shown in figure 8 was developed and used in a difficult situation on Shoal Creek.

Instead of a log-cabin crib on each side of the waterway, flaring wings one timber thick were extended around the ends of the earthen embankments. Long timbers cut from the trunks of large juniper trees were placed end to end in a semicircle and tied into the bank by short riders. Other courses of logs and riders were then placed directly above the first. Floor and wings were woven, spiked, and tied with galvanized wire. The timber wings were backed by a continuous rock wall of large boulders, laid close together and puddled in place against the ends of the embankment to prevent seepage.

The timber and rock spillway at Shoal Creek deserves special mention. This stream is subject to great fluctuations during the spring run-off and to heavy floods from torrential rains. In normal years all the water, beginning with the first spring run-off, is needed for irrigation. Diversion dams had been built by the water users of sand and clay, interspersed with juniper boughs and straw held down by rocks; but these never had been able to withstand even a slight freshet. In flood seasons the sandy stream bed, 380 feet wide, was a bog of quicksand.

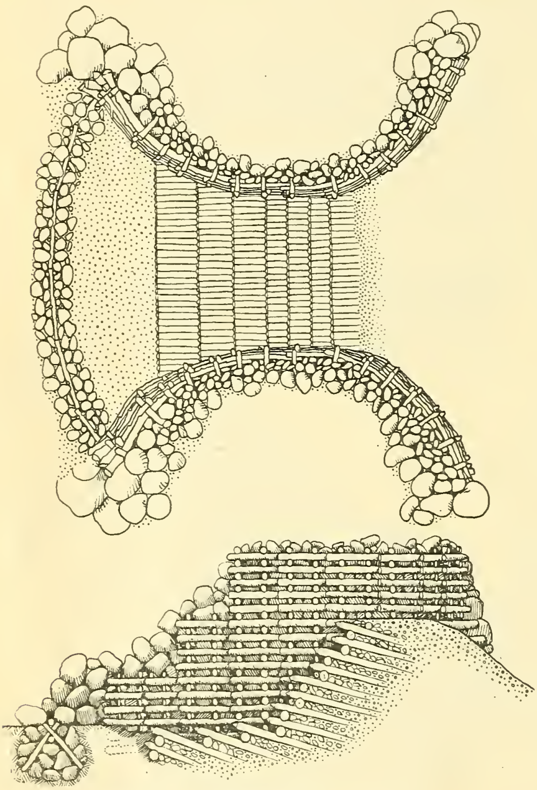

FIGURE 8.—Timber spillway of type B.

The combination gravel barrier and diversion dam was built, with spillway capacity to pass 2,000 second-feet of flood flow, upon a foundation of loose sand at the intake of the canal system. An excavation for foundations was made 20 feet deep across the stream bed, to a layer of silty clay with embedded boulders. A flow of about 2 second-feet of water percolating through the sand and gravel was intercepted. The excavation was filled with clay, puddled in place, and a barrier embankment of the same puddled material was built with its top 14 feet above stream-bed level. Midway of the channel the spillway of juniper timbers and rock was constructed, with its crest 6 feet above the stream bed.

The structure has shown no leakage around the spillway wings and in 7 years has withstood three torrential floods. The first flood caused considerable cutting in the loose sand downstream. The cuts

were filled with boulders 1 or more cubic yards in size and with smaller boulders, which have settled into a permanent mass. Gravel is deposited above the barrier, but much of the sand is carried down the canal to a sand trap, where it is flushed out.

The advantage of timber and rock construction is that it can be built with a minimum of expense. The greater part of the materials used are generally available at the site; skilled labor is not required, and where the labor is furnished by the interested parties, the cash expenditure may not exceed 10 percent of the total cost. The disadvantages of this type of construction are its comparatively short life and its permeability. One type of timber and rock spillway is shown in figure 9, *A*.

RUBBLE CONCRETE

Rubble concrete is one of the most satisfactory materials for spillway construction. Its cost is more than that of timber and rock, but it is more permanent and impervious. It has the additional advantage of resisting the abrasive effect of water-borne sand and gravel, if the rubble is made of boulders placed as closely together as possible with their outer surfaces projecting into the water to protect the concrete mortar which is used to fill the interstices.

The investigations herein reported indicate that the best rubble structure is one that will stand without mortar and in which concrete is used merely to fill the voids and to decrease leakage. When available, pear-shaped boulders, 2 feet or more in length, should be used. For the floor and crest they should be laid with the smaller ends tilted downward and pointing upstream. After one course is laid, concrete should be spaded between the rocks to within 6 or 8 inches of the top surface. The second course is laid so that each rock rests upon two boulders in the lower course. A rubble-concrete spillway is shown in figure 9, *B*.

The low cost of rubble masonry has appealed strongly to those in charge of flood-control undertakings. Rubble masonry has been placed by common labor furnished by persons who would receive the benefits and who were glad of the opportunity to work out their assessments. The following figures cover all items of expense in the erection of a rubble-masonry spillway.

Boulders, 55 loads, approximately 85 cubic yards	No cost
Sand, 7 loads, approximately 11 cubic yards	Do.
Gravel, 14 loads, approximately 22 cubic yards	Do.
Cement, 196 bags	$186. 20
Team work	190. 00
Common hand labor	252. 00
Lumber, gas, oil, and miscellaneous	31. 80
Total for 85 cubic yards of masonry	660. 00

In this case, the cost was $7.76 per cubic yard, two thirds of which was for labor performed by the water users.

Massive spillway structures of rubble masonry built on alluvial fill, without the aid of sheet piling or comparable substructure, have withstood heavy floods successfully. One such spillway 79 feet high, resting upon alluvium, has resisted the action of torrential floods for 6 years without showing the slightest indication of failure. Similar structures of lighter proportions built on sand and gravel formations

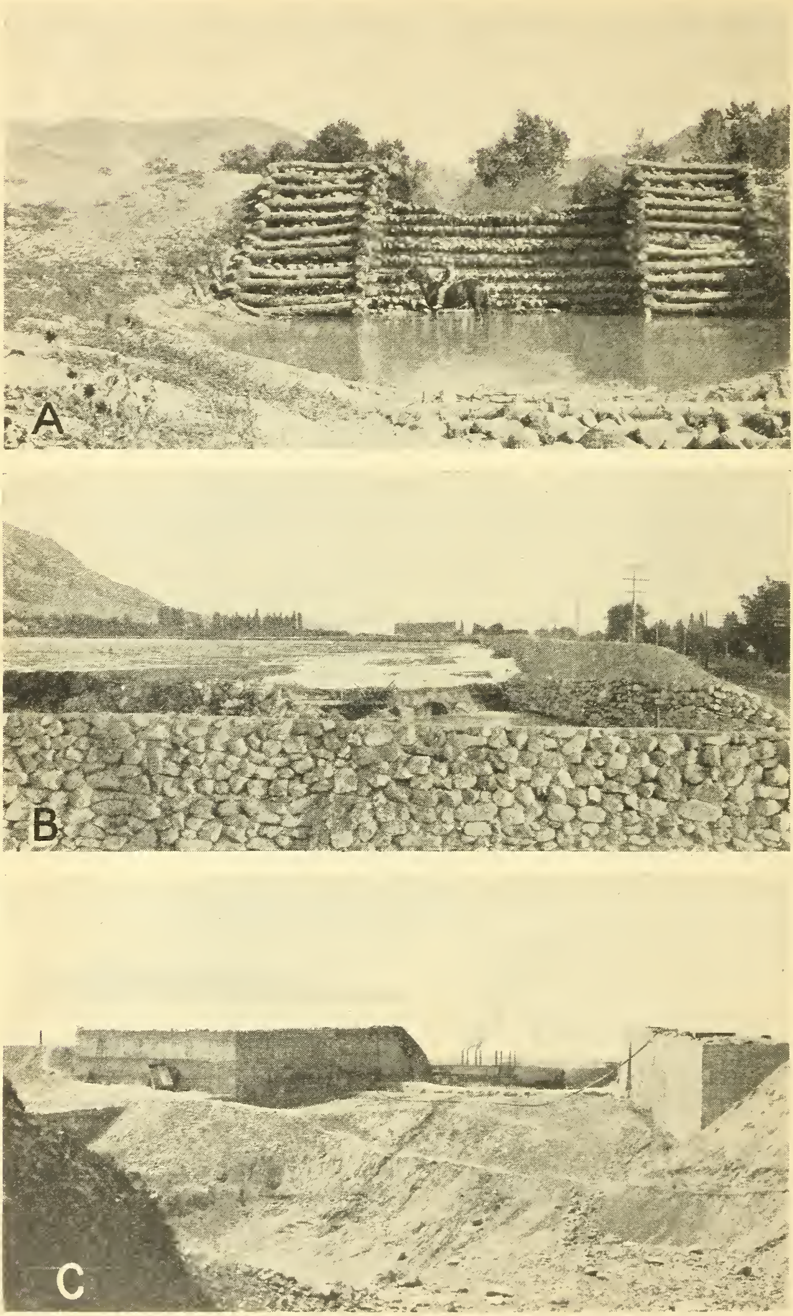

FIGURE 9.—*A*, Timber and rock spillway, Kanosh Creek, Utah; *B*, rubble masonry spillway, Willard, Utah; *C*, spillway with reinforced concrete wings, Kessler Canyon, Utah.

in natural stream beds have been severely tested by floods without showing the slightest settlement or other damage. In most cases substructures of the kind usually employed with reinforced-concrete construction on such foundations would be prohibitive in cost, and apparently are unnecessary for spillways in flood-control barriers.

REINFORCED CONCRETE

Reinforced concrete is not in general use for barrier spillways, but there are some conditions under which its use is advisable. In general, it does not withstand the erosive effect of sand and gravel, and its cost is generally greater than that of other materials. Skilled labor is required for form making, and the cement must be purchased, so that a large part of the total cost must be paid for in cash. On a large job where accurate records were kept, reinforced concrete cost $30 and rubble masonry less than $8 per cubic yard.

Especial care must be taken in getting good foundations for concrete structures so that there will be no settlement or cracking. A spillway with reinforced concrete wings is shown in figure 9, *C*.

STILLING POOL

The purpose of the stilling pool is to settle out the finer materials carried by the flood waters such as fine sand, clay, and silt. Its size is dependent upon the amount of fine material carried by the stream and the degree of clarity of water desired. Usually, for irrigation, there is not sufficient fine material in the debris derived from steep mountains to necessitate a very large stilling pool. If the basin above the barrier is properly maintained, the pool will be oval-shaped, with a depression immediately above the spillway and the short axis of the oval extending upstream. As gravel is brought down and deposited adjacent to the dikes and barrier and the spillway raised, there is formed a settling basin which will automatically become larger as the barrier and wasteway are built up, and the crest of the spillway is raised.

DRIFT DAMS

The purpose of drift dams is to direct the flow of spring floods from place to place within the basin. These structures are temporary and are moved or else covered up as the gravel flow is light or heavy. These dams are built of trees and brush, of posts to which wire screen is tacked, or of posts interwoven with willows and brush. The materials most used are cottonwood or cedar trees held in place with posts or boulders. Any materials may be used that will direct the stream flow. The number of drift dams and their location is entirely a matter of judgment, but usually 2 to 5 will be in use at the same time. Figure 6, *B* shows a fence of woven wire used for a drift dam.

EXAMPLES OF BARRIER SYSTEMS IN UTAH

NEPHI

Nephi is situated in an area devoted mainly to dry farming, but obtains from Salt Creek a limited supply of irrigation water for the production of diversified crops. Salt Creek carries in the early spring a considerable volume of water with a heavy load of gravel, but in summer has a very small flow. It is necessary that the high-water

flow be fully utilized, and it has long been the practice at Nephi to begin irrigating early.

Every spring great quantities of gravel were carried into the irrigation canals, which had to be cleaned out with teams and scrapers. It finally became necessary to work night and day during the spring run-off to keep the canals open so they could convey a part of the flow to crops.

The town is situated at the vertex of the Salt Creek fan, just below the mouth of the canyon. The irrigated lands lie farther down the slope, and the supply canal and principal laterals pass through the town. Frequent scraping of gravel from the canal and laterals on to the streets resulted in mounds as high, in many places, as the tops of first-story windows of houses. In 1922 the city authorities notified the irrigation company that the dumping of gravel in city streets would no longer be tolerated.

Among methods of control proposed was the barrier system. Because of its simplicity and promise of effectiveness, it met with the unanimous approval of the stockholders. Two barriers were constructed in 1922 and 1923, one above the first canal diversion dam and the other 7 miles above the town. The crest of the spillway of the upper barrier was built 7 feet, and that of the lower barrier 5 feet, above the bed of the stream. Both spillways had wing walls 4 feet high, which provided a freeboard of about 3 feet at normal high-water stages.

The cost of the structures was $3,100 in labor and a cash outlay of less than $50. In 1922 alone, prior to the erection of the barriers, the irrigation company had expended merely for scraping gravel $4,800, or $1,700 more than the labor cost of constructing the two barriers.

The structures have been in operation 10 years, and have held back all of the sand and gravel carried by the stream. There has been no expense for maintenance. The pools above the spillways have become partly filled with sand and silt, but the deposition of gravel has never advanced beyond the upper edges of the original stilling pools. Under present conditions it appears that the structures should give good service for another 10 years without any increase in height of spillway. It would be desirable, however, to scrape sand and silt to build up the embankment with material from the pools prior to the time when necessity actually requires it. It is intended to raise each barrier when deposition upstream reaches a stage where sand and gravel may go over the spillway.

The lower barrier on Salt Creek was built to check the sand and gravel which the stream might pick up after being unloaded at the upper site. In 1923 it was put to a severe test by a torrential flood from a side channel. The flood was preceded by a rolling mass of mud and debris from 6 to 8 feet high, which was followed by a flow of thick muddy water. The spillway was entirely inadequate to carry the flow, and for 20 minutes the stream filled the floor of the canyon from wall to wall and poured over the barrier embankment to a maximum depth of about 16 inches. After the first flush the flow gradually subsided until, in another 20 minutes, the spillway carried the entire stream, which continued to run for nearly an hour. The structure endured this test without damage, although the embankment and wings had not been fully completed. The flood filled the

stilling pool with mud, and it was deemed advisable, when the wings were built to their full height, to raise the spillway crest 18 inches. The cost of this work is included in the $3,100 before mentioned.

The works on Salt Creek benefited not only the irrigators, but also the city. The removal of gravel from the stream made it possible to utilize the water through a new municipal power plant, which approximately doubled the local supply of electrical energy.

WILLARD

Willard is located at the vertex of a large cone which has its base at the shore line of Great Salt Lake. Willard Canyon is precipitous and devoid of open spaces where a flood stream might spread and drop a part of its load.

In August 1923 a downpour on a recently denuded watershed caused a mud flow containing boulders and gravel to sweep in three paths through the town to Main Street, where mud, boulders, and the wreckage of dwellings and barns were dumped in profusion to a depth of 6 feet or more. The former stream channel above Main Street, which had a depth of from 30 to 40 feet, was obliterated. In its place was a ridge of boulders over 800 feet wide. Rehabilitation was placed in charge of a State relief committee appointed by the Governor.

A by-pass channel 10 feet deep and 16 feet wide, with a slope of from 4 to 10 percent, was constructed 7,000 feet along the course of the stream bed, at a cost of $12,000. The committee constructed this channel to handle all normal run-off, including spring freshets from melting snows, the maximum volume of which does not exceed 250 cubic feet per second.

Spring high water began in 1924 on May 3. On May 8 the new channel was full to the top of the banks with gravel, notwithstanding that the State roads commission had kept teams with plows and scrapers at work in three shifts in an effort to pass the debris along. Culverts beneath the highway and the railroad tracks were blocked, the tracks were buried under sand and gravel, and valuable farmlands not damaged by the flood were being rapidly covered.

When the by-pass channel failed to function, the barrier system of control previously recommended to the committee was given a trial.

The area along the course of the old channel on the east side of the State highway at the north end of Willard was covered with huge boulders. There were no lateral embankments between which a barrier might be erected, and there was nothing of which to build embankments or barrier except the boulders, most of which were more than 2 feet in diameter. Men with teams dragged and rolled the boulders into position along the east boundary of the highway and along the margins of the flood scar to an intersection with high ground at the mouth of the canyon. This formed a basin some 1,500 feet long and 300 feet wide where the flood flow could be checked and its burden of detritus deposited. Wet straw from the bottom of old stacks and coarse barnyard manure were placed on the upper sides of the ricks of boulders, and held down by smaller rocks. This construction checked the flood stream, and the leaks were sealed by deposition of fine silt. At the end of the first day the leakage through

this crudely fashioned barrier did not exceed 2 second-feet in a length of approximately 1,000 feet.

The bypass channel had been excavated near the north boundary of the barrier basin in the ridge left by the flood. The new ground surface sloped away from the channel in both directions, but the main slope was to the southwest toward the center of town. In order to check the velocity of flow, the stream was turned southward at the mouth of the canyon and allowed to spread over the bed of boulders as far as the boundary dikes. It was then directed to the west until it reached the barrier along the highway, and from that point northward on an upgrade to an improvised spillway emptying into the bypass channel. To prevent the stream from overflowing the south bank during the high stages that occurred each night for several days, sandbags were used until enough fine materials were washed into place for building up the marginal embankment and barrier.

An important factor in the barrier system of control developed in connection with the highway crossing. Until the stream was diverted into the barrier basin above the highway, a force of from 10 to 12 teams drawing plows and tongue scrapers had been kept at work in the channel below the highway in an effort to retain the stream within bounds and force it to carry its load of gravel on to lower levels. In spite of this effort, the stream bed had been raised higher and higher until on May 8, 1924, it had reached a level above that of adjacent lands, and the stream was spreading beyond control. On the evening of that day diversion was made into the barrier basin where the stream was completely unburdened before it was returned to its channel under the highway crossing. Erosion lowered the stream bed 18 inches that night, and continued until at the end of 5 days a permanent bed was reached at a depth of 8 to 10 feet. The teams were no longer required in the channel.

The barrier has held back the sand and gravel, and has controlled several torrential floods, three of which were severe and carried large boulders. A survey of the barrier in the summer of 1932 showed that approximately 119,000 cubic yards of eroded material had accumulated back of the barrier.

An outstanding feature of the control works at Willard has been the utilization of the spring floods in building up the embankments around the barrier basin. Deflectors at the mouth of the canyon force the stream, with the large quantities of gravel and sediment which it carries at high-water stages, to one side or the other into the floodway around the outer margin of the basin.

The inner margin of the floodway was first defined by a fence of closely woven wire with posts heavily braced (fig. 6, *B*). Gravel deposited against this fence and between it and the dike was scraped onto the dike to keep it above flood height. When the fence had been covered with gravel, a cribwork of stumps from damaged orchards was built above it, and straw, rocks, and tree tops were used in stopping heavy leakage through the crib. Year by year the dikes about the basin have been raised in this way until what was a ridge after the flood of 1923, has become a depression through the bottom of an area that slopes from all sides toward the spillway. The deflectors at the upper end of the basin were built of logs, timbers, brush, straw, and rocks placed during floods and soon covered by sand and gravel deposited by the water.

This method of building embankments may sometimes be used in constructing levees along streams with considerable fall that carry heavy burdens of debris, or in constructing dams for storage reservoirs on mountain streams, where the cost of construction by other methods might be prohibitive. The work done at Willard indicates that this type of construction will cost from 1 to 3 cents per cubic yard as compared to 25 cents to $1 for materials mechanically transported into place. A stream in flood carrying a full burden of sand and gravel is easily turned from one course to another. A tree felled across a channel or a log placed across a stream with some brush or a few limbs, preferably having numerous small branches and leaves, will change the course of a raging torrent. A stream does its best work in carrying material into place when at its maximum stage, and is not nearly so difficult to control as some might fear.

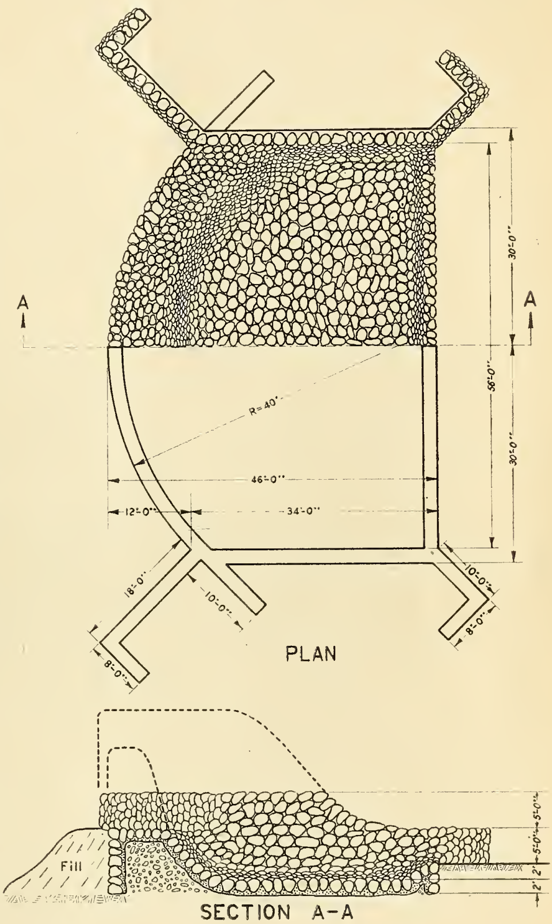

FIGURE 10.—Plan of Mount Pleasant spillway.

MOUNT PLEASANT

Pleasant Creek traverses a highly developed farming area and flows through the center of the principal town of the district. The stream is subject to frequent severe summer floods. In 1918 a violent torrential flood swept through city streets and across farming lands, and left a mass of boulders and debris. Soon afterwards a plan was devised for a floodway or by-pass around the town, at an estimated cost of $40,000, but legislative support for this plan failed.

In 1924 the Bureau's engineers suggested the construction of a simple barrier of earth with a rubble-masonry spillway. Right-of-way negotiations and other difficulties caused delays even after work was begun; but in 1928 the flood-control system, costing $8,000, 90 percent of which was for labor, was completed. In 1929 the barrier was given a severe test by a deluge of mud and rocks of greater volume than that

of the flood of 1918. All heavy debris was deposited above the spillway and the flow was equalized at the barrier so that the natural channel carried the water through the city, past farm lands, and into Gunnison Reservoir. Citizens of the community who were responsible for financing the building of this structure stated that the protection afforded the city and the farm area in 1929 more than repaid the expenditure. Figure 10 shows the details of spillway design.

KESSLER CANYON

The run-off from a part of the Oquirrh Mountains flows through Kessler Canyon and then into Great Salt Lake about 24 miles west of Salt Lake City. The channel traverses the site of Garfield smelter, one of the large industrial plants of Utah, and crosses an important transcontinental highway and three railroads.

Prior to June 1927, 22 small check dams of concrete or stone masonry and steel had been built across the bottom of the main channel to prevent erosion and hold back debris, and the storage basins above all of them were filled with rocks and gravel. In that month a torrent heavily charged with mud, tree trunks, and huge boulders came down the channel, doing damage to the amount of about $150,000. The torrent swept all but one of the dams from their foundations and carried away all the material that had been deposited behind them.

The check-dam system having failed, the barrier system of control was adopted. The principal construction consists of an embankment 3,200 feet long across the mouth of Kessler Canyon, with a rubble-concrete spillway (fig. 9, *B*). The embankment is 15 feet high, and has a base width of 150 feet and a crown width of 40 feet. The upper crest of the spillway is 64 feet, and the tops of the wing walls are 79 feet above the stream bed. Such height was required because of the depth of the gorge that had been cut through the deltaic formation of old Lake Bonneville above the smelter plant. The spillway rests upon alluvium, and although this might be considered hazardous for so high a structure, thorough examination 3 years after the system was completed disclosed no indication of settlement or of cracks.

Parts of the spillway were buried by flood action five times during construction. The first two floods filled the excavation for the foundation and delayed construction. The last three filled the channel above the works more compactly with debris than would have been possible by mechanical means and were decidedly beneficial. The masonry was not damaged by the bombardment of boulders, although the concrete was still green.

In July 1929 the control works were severely tested by a flood of volume and destructiveness approximating that of the 1927 flood. The structures were still unfinished, but they controlled the situation and prevented damage to the smelter plant, the highway, and the railroads. In more recent floods the works have controlled conditions satisfactorily.

Besides the main channel in which the spillway is located, three channels from minor drainage areas are crossed by the main embankment. Each has its cone with base just above the barrier and vertex back on the open delta. The channels above the dike slope to the spillway at an average grade of about 3 percent.

To maintain a stilling pool of considerable size above the structure at all times, the spillway and embankments will be raised from time

to time. An electric tower drag-line excavator with a reach of 500 feet has been erected on top of the principal wing of the barrier, ready to open up the channel above the barrier and raise the embankment when necessary.

FARMINGTON

After the flood of 1923 in Farmington Canyon, an artificial channel similar to that at Willard was excavated from the mouth of the canyon to the low lands. However, this channel was completely filled with gravel within a week after high water came, and a thick layer of sand and gravel was deposited on lands that had not otherwise been damaged.

In 1924 a barrier with rubble-concrete spillway was constructed across the mouth of the canyon below the most extensive deposits of boulders and above the State highway. The spillway has been raised three times. The last addition, in 1931, brought the crest 23 feet above the stream bed (fig. 11, *A*).

The original surface of the boulder deposit left by the 1923 flood, which had a slope of between 7 and 12 percent and extended 4,000 feet above the barrier, has since been entirely covered by gravel and boulders brought down by spring high waters and torrential floods.

KANOSH

In the fall of 1923 a barrier with a suitable spillway was built at the mouth of Corn Creek Canyon, primarily to check the immense volume of gravel which flowed annually into irrigation ditches. The stream is subject to frequent flooding in the summertime, and each flood washed out diversion dams and caused loss of water before new structures could be built.

The barrier has eliminated the expense of cleaning gravel from canals and of building new diversion dams and has successfully controlled several summer floods. The stilling pool above the barrier serves as an equalizer of fluctuating stream flow, and materially increases the efficiency in delivery and application of the water. The barrier cost $1,200, all in labor.

FILLMORE

For many years prior to 1923 Chalk Creek at Fillmore was subject to frequent floods in summer and to great flows of gravel in the spring. Efforts had been made to use the entire flow of the stream for irrigation, even at flood stages, but these failed because of the impractical methods used for holding the stream within bounds. Losses during high water amounted to as much as 75 percent of the flow.

In the early spring of 1923, a barrier was built across Chalk Creek Canyon at the upper edge of Fillmore, where the fall of the valley is slight and where the stream bed normally spreads over a channel about 300 feet wide. The barrier and spillway cost $1,500, most of which was for labor, and resulted in an annual saving of more than $3,000.

The stilling pool, which extends 500 feet upstream from the barrier, has filled so that the barrier and spillway should now be raised. Gravel has been deposited upstream for a distance of 2,500 feet, but has not been carried closer to the crest of the spillway than the upper end of the stilling pool.

PAROWAN

The watershed which feeds the stream from Parowan Canyon covers an extensive area of high mountains and a long range of low foothills. The area is subject to torrential floods and to a long period

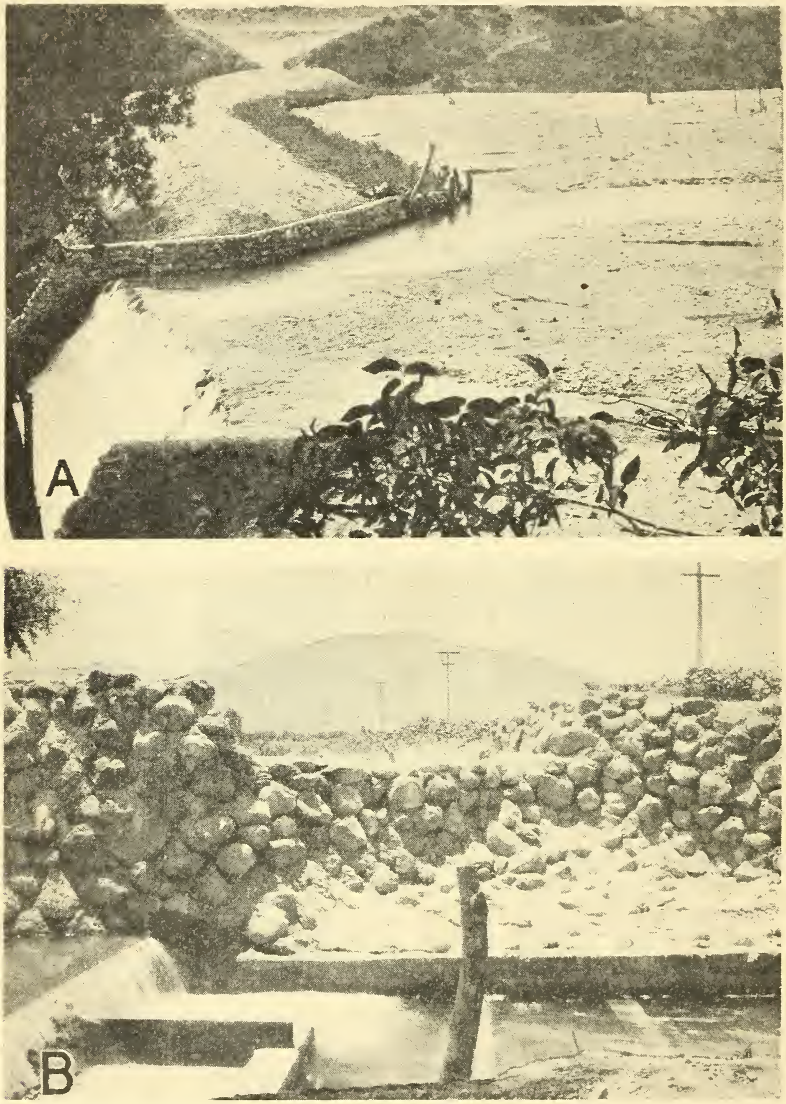

FIGURE 11.—*A*, Farmington barrier spillway just before being raised in 1931; *B*, looking upstream through Santaquin barrier spillway—barrier basin lies at one side of low-water channel. Immediately to right of weir crest, placement of boulders in two vertical lines is faulty; elsewhere it is fairly good.

of high water from melting snow. Parowan is situated at the mouth of the canyon, where a huge alluvial cone spreads through the valley on a relatively light slope to Little Salt Lake 9 miles away. On the surface of this fan is the farming area of the community.

A series of floods, followed by drifting gravel at high-water time, filled the natural channel and left the town and the farms below subject to serious damage. When attempts were made during the spring run-off to use the stream for irrigation, sand and gravel filled the canals and ditches.

To hold the stream within bounds and to eliminate some of the gravel, a partial levee had been raised along the channel above the town. In 1925 the levee was enlarged, a barrier was built across the channel to high ground, and a rubble-concrete spillway was erected between the embankments. Since that time the community has been saved six times from damage by torrential floods. The irrigation system is free of gravel flow, and the entire flow of water is utilized in crop production.

PERRY CREEK

Perry Creek is a small stream that normally carries a considerable load of sand and gravel and is subject also to summer floods that leave large deposits of heavy material. Attempts were made to use all the water for irrigation, but most of it was lost because the flow was not controlled. Following a flood in 1923, plans were made for a barrier and spillway, but the structure was not built until 1929. In the meantime, adjacent farm lands and the State highways were flooded each year.

In an effort to by-pass the sand and gravel, a deep, narrow channel about 3,500 feet long was dug in 1924, and again in 1928. The channel was obliterated by each flood, and the stream continued to cover adjacent farms and the highway. The barrier was built in time to control the 1929 run-off, and ever since then all the water of the stream has been used in irrigation and the ditches have been free of gravel and sand. The cost was $2,200. The water users testify that the benefits obtained through increased use of the stream during the first year alone justified the expense.

SPECIAL CONTROL PROBLEMS

The problems in connection with flood and gravel control are numerous and varied, and each situation calls for special study and individual analysis. Solutions of some typical cases in Utah are outlined below.

CONTROL OF GRAVEL AT INTAKE TO HIGH-LINE CANAL

Where diversion for irrigation or power is made above any practicable site for a barrier system of gravel control, the canal must be closed during the high-water flow in spring when the stream is filled with heavy debris unless some special device is installed for separating the water from its burden.

At Willard the principal diversions for irrigation are made above the barrier basin. A constant volume of water, up to the capacity of the delivery system, is required for irrigation because of the very limited size of the stream during midseason after run-off from melting snows is over. To meet this situation, the structure shown in figure 12 was constructed. It is built on solid rock, and serves not only as a permanent diversion dam but also as a means of eliminating the gravel and most of the sand from the irrigation water.

At the intake to the canal above the diversion weir, a considerable length of adjustable flashboards approximately parallel to the direction of the stream is arranged in a manner to skim off the surface water. Downstream from the flashboards the channel for diverted water is deepened to the level of the stream bed for about 60 feet, past the dam and stilling pool. There the water for irrigation flows over a bulkhead 8 to 10 feet high with its top at the elevation of the irrigation canal. The real intake to the canal is through a regulating gate just below the bulkhead. The deep section of channel is a settling pit, from which a sand gate just in front of the bulkhead leads back into the main channel.

A surplus of water is taken in over the flashboards, so that the sand gate may be kept open during flood time. The gate draws

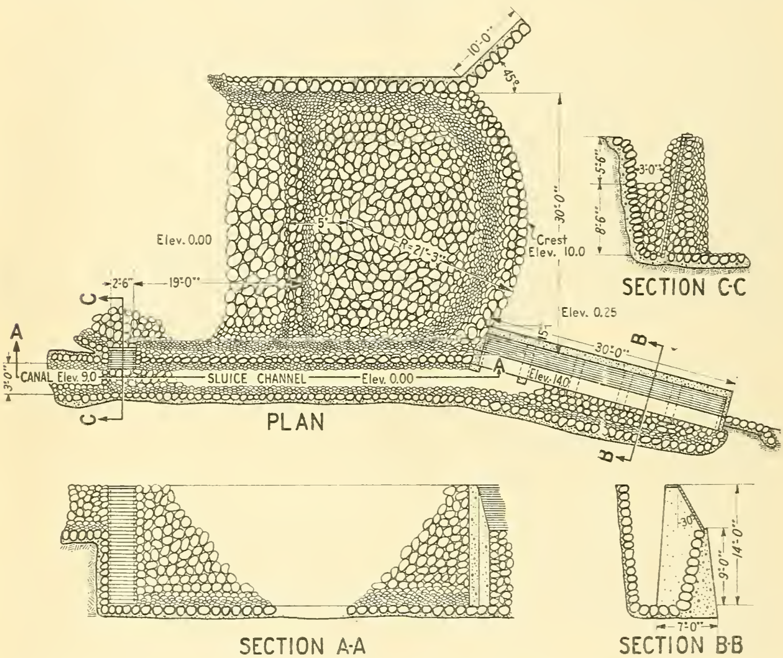

FIGURE 12.—Plan of diversion dam and gravel control works at intake to Willard high-line canal above flood control barrier.

off the sand and gravel entering the canal. When the entire stream is carried by the high-line canal the sand gate is closed, but it may be opened to flush out the sediment that collects in the pit above the bulkhead. If the gate is opened the entire stream may be turned out through the sluiceway to wash the settling pit clean. This method of cleaning requires but a few minutes, and may be used every few hours or every few days according to the amount of sand and gravel being carried by the stream.

SANTAQUIN GRAVEL TRAP

In 1922 a gravel trap on Summit Creek above Santaquin was planned. The original design called for an embankment across the lower end of a natural basin and for a spillway leading into the

channel above a measuring and dividing weir at the intake structure for the canal system. The water users built, however, a series of net-wire fences across the channel to intercept the gravel, because this was cheaper than a structure to divert the stream into a natural depository where it could spread and unload before being turned in to the canal system. All the water was needed for the cultivated lands.

The wire checks failed to hold back the gravel, and canal cleaning became so expensive that in 1926 the original plan for flood control was adopted (fig. 11, *B*). The control structure was completed in 1927, at a cost of $500 for embankments and $660 additional for the spillway. Previously the cost of ditch cleaning had averaged more than $2,000 annually, and much of the water was lost. With the control works, cleaning was reduced to the removal of weed growths and sediment, and all the water was made available for irrigation.

PAYSON CANYON

Payson Creek, Utah, flows under the high-line canal of the Strawberry Valley irrigation project through a large inverted siphon, below which the stream bed rises to the level of the canal and then falls gradually to the valley. At the opening of the irrigation season each year the siphon usually was clogged and the concrete-lined canal often was filled, for more than 500 feet, with rocks and gravel. Summer floods frequently caused similar clogging of the siphon and filling of the canal, with loss in water and labor to the farmers. The value of water lost while the canal and siphon were being cleaned was even greater than the expense of removing the debris.

In 1926 a small barrier and spillway were built in Payson Canyon, which have eliminated the trouble at Strawberry Canal crossing and have cleared the creek of debris so that the entire flow is now used for irrigation. The cost was $1,200 in labor.

SUMMIT CREEK

At Summit, Utah, a combination flood control, gravel control, and equalizing reservoir was built. Moderate floods and high water are diverted into a small basin on one side of the drainage channel where a dam provides storage and checks any flood that comes into it. The reservoir has an outlet gate through the dam and an overflow spillway into the natural channel. The basin is large enough to hold the flushes from melting snows on warm days, and equalizes the flow for irrigation. On hot days, when the stream is almost valueless because of evaporation and seepage losses, enough water can be stored to furnish a large stream that can be delivered without a high percentage of loss.

CONCLUSIONS

Ten years of study have indicated that it is impracticable to construct channels which will carry away the debris brought down by torrential floods in mountain streams or the gravel flows that follow. It appears that any such channel will fill rapidly with detritus and overflow at the point where the grade changes from heavy to light.

The barrier system of flood and gravel control developed in these investigations appears to have a broad range of application. The principles evolved in the barrier system are based upon natural laws, and may be used wherever floods carry a heavy load of debris. The study covered a variety of conditions, and some of the structures have been tested severely. Every structure built in accordance with the barrier principles has thus far served its purpose fully and has provided complete control of flood waters and gravel.

The success of the barrier system is dependent upon the amount of reasonably smooth surface over which the flood stream may spread before it reaches the stilling pool above the barrier. The lateral embankments merely define the limits of the depository. The wider they are apart, the less the height needed to give protection against flood damage. If the flood is permitted to spread laterally over a broad surface there is less danger that the pool above the barrier will be filled with debris. The tendency of the successful barrier is toward complete unloading of the flood stream on the surface of the cone above the barrier, where the lateral embankments are widely separated. Where the unloading process is complete, the fine sand and silt are dropped in the stilling pool. The natural channel will usually carry the water after the heavy detritus has been dropped.

An outstanding feature in the barrier system is the method by which a stream carrying a capacity load of sand, gravel, boulders, and mud may be used in building the lateral embankments and the barrier of a control basin where a natural site does not exist. The method is so simple and inexpensive that it may be used to build marginal embankments for control works at any section of an alluvial cone, even though the surface of the cone is higher than the natural ground on either side. This principle may be used also under some conditions in building levees along streams that overflow their banks because of the debris they transport to lower levels.

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